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Cellular plastics for building

In recent years there has been a considerable increase in the use of plastics in buildings. This digest discusses foamed and expanded plastics whose good thermal insulating and acoustic properties combined with low cost and weight and ease of handling can make them useful building materials; it replaces Digest 93 which is now withdrawn.

The term 'cellular plastics' is used for both foamed and expanded materials. Foamed plastics may have an open or closed cell structure; expanded plastics have a substantially closed-cell structure. In open-cell materials, the cells are mostly interconnected, permitting free movement of air and vapour through the volume of the material, whereas closed-cell materials are substantially air- and vapour-tight. Table 1 lists the cellular plastics at present used to any appreciable extent in building. Table 2 lists some properties of cellular plastics in the more commonly available forms likely to be of most interest to builders and designers. It has not been possible to obtain all these data at first hand, or to obtain data determined under the same conditions in every case. To give roughly comparable data, some figures have been estimated from information obtained under somewhat different conditions. Exact data (eg for specifications) should be obtained from manufacturers.

Table 1 Cellular plastics

Material	Description	Availability
Expanded polystyrene 'bead-board'	White rigid material formed by the fusion together of expanded beads of polystyrene. Also obtainable in a pre-compressed form that is more flexible and resilient, and in granular form as unfused expanded beads.	Sheets a few millimetres thick and slabs 13 mm and more thick; also shaped forms for special insulating jobs. Densities normally 16–40 kg/m³ (see also BS 3837 and BS 3932).
Extruded expanded polystyrene	White or light-coloured material formed by a simultaneous extrusion and foaming process.	Boards up to 50 mm thick; also boards with a denser surface skin. Densities normally 32–40 kg/m³.
Expanded polystyrene beads and granules	White material formed by granulating bead board or as unfused expanded beads.	Density normally 12–24 kg/m³; used for loft and cavity fill insulation.
Expanded polyvinyl chloride (pvc)	Yellow to deep brown rigid material, formed by foaming pvc when in a plastic state, and cooling to solidify.	Boards up to about 100 mm thick, with cells sized 1 mm upwards. Densities 24–128 kg/m³ (see also BS 3869).
Foamed urea-formaldehyde (uf) resins	White friable material, usually formed by foaming an aqueous dispersion of resin and curing it in this condition.	Slabs of density 32 kg/m³ and upwards. For building application, generally foamed *in situ* to produce a 'cotton-wool' texture and density as low as 6 kg/m³.
Foamed phenol-formaldehyde (pf) resin (phenolic foam)	Pink or deep red rigid material, somewhat friable, made by foaming and subsequently curing phenolic resin.	Sheets, blocks, moulded sections of density 48 kg/m³, or higher, if required.
Foamed polyurethane (urethane foam)	Colourless to deep brown material, sometimes artificially coloured. Prepared from two liquid components which are sometimes pre-expanded before complete chemical interaction and curing occurs.	Rigid or flexible foam in sheet and block form and in shaped forms for special jobs. The rigid foam is also available as a sandwich between layers of thick paper and in other laminates. May also be foamed *in situ* in cavity walls or applied by spraying.
Foamed polyurethane granules	Granulated urethane foam.	Used for cavity fill insulation.

Prepared at Building Research Station, Garston, Watford, WD2 7JR
Technical enquiries arising from this Digest should be directed to Building Research Advisory Services at the above address.

Table 2 Typical properties of cellular plastics used in building

Material	Density	Compressive stress at yield point	Coeff of linear expansion	Thermal conductivity	Max temp for continuous operation	Seven days' water absorption	Water vapour resistivity [1]
	kg/m³	*$\times 10^4$ N/m²*	*$\times 10^{-5}$ per °C*	*W/m°C*	*°C*	*Vol. %*	*MN s/gm*
Expanded polystyrene:							
bead board	16	7	5–7	0·035	80[2]	3·0	270
bead board	24	12	7	0·033	80[2]	2·5	420
extruded	32	27	7	0·035	75[2]	1·5	1300
extruded, with surface skin	40	27	7	0·032	75[2]	1·0	1300
Expanded pvc	40	27	3·5	0·035	50	3·0	800
Expanded pvc	72	90	5	0·043	50	3·8	1300
Foamed urea-formaldehyde	8	Negligible	9	0·038	100	10	22
Foamed phenol-formaldehyde	48	14	2–4	0·036	150	High (open cell) 35 Fairly low (95% closed cell) 240	
Foamed rigid polyurethane (fluorinated hydrocarbon blown)	32	17	2–7	0·03–0·07[3] 0·01–0·03[4]	100	2·5	360

[1] These temperatures may be slightly lower for flame-retardant grades. Manufacturers' advice should be sought in cases of doubt.

[2] 15 MNs/g is considered a suitable resistance for a vapour barrier in building applications but because of the risk of interstitial condensation within a cellular material, an additional vapour-sealing skin may be required.

[3] CO_2 blown.

[4] Fluorocarbon blown.

Expanded polystyrene

Expanded polystyrene is manufactured in two different types with distinct properties. The type referred to as 'bead board' is formed by the fusion together of pre-expanded beads of polystyrene. The second type is manufactured by a continuous extrusion process and has a simpler and more regular cell structure than bead board. Both are available in grades according to density and fire properties.

BS 3837 for 'Expanded polystyrene boards' is currently being revised to include both 'bead board' and 'extruded board' in various forms. Classification is to be in terms of physical properties; a range of boards of different compressive strengths and permeabilities is being defined, corresponding to the materials which have become available since the standard was first published in 1965. BS 3932: 1965, *Expanded polystyrene tiles and profiles for the building industry,* covers products which are usually made by the bead-fusion process.

The principal application of expanded polystyrene is for thermal insulation. The thermal conductivity (k) for material of 16 kg/m³ density, determined at normal building temperatures, is 0·035 W/m °C, which is better than that of most other materials available. Material with a density of about 32 kg/m³ has an even lower k-value; however, the benefits of this for thermal insulation do not by themselves justify the extra cost. Advantages of expanded polystyrene include its extreme lightness, attractive appearance, the ease with which it can be handled and fixed, and surprisingly good mechanical properties for a material with so little weight. It is odourless, chemically very stable, resistant to fungal attack, and in the tropics only exceptional cases are on record of its being attacked by termites. Birds have been known to use it for lining their nests, particularly when they can find a perch from which to peck at it.

The water vapour permeability of expanded polystyrene is lower than that of most insulating boards, although it is not usually low enough to allow a vapour barrier to be dispensed with in situations where condensation is likely. Similarly, though it has only low water absorption, it is enough in very wet conditions to cause a loss of thermal insulating properties; a waterproof barrier should be used in these situations.

The recommended maximum working temperature is 80 °C which is too low for some applications, e.g. insulating hot water systems. The material is softened by most of the common organic solvents and by aromatic organic solutions which are present in many paints, adhesives and some petroleum fuels.

Table 3 Applications of cellular plastics

Material	Applications	Comments	Behaviour in fire
Expanded polystyrene	Lining of walls and skin roofs, insulation of flat roofs and concrete floors. In floating floor construction to absorb impact sound. Wall and ceiling tiles; insulation of cold water pipework. Shaped formwork for concrete. Cavity wall and roof insulation.	Attractive appearance; good thermal insulation; relatively low softening point; attacked by most organic solvents. If in contact with pvc, interaction causes loss of plasticiser and embrittlement.	Burns fairly rapidly; often softens and collapses. Flame-retardant grades are available.
Expanded pvc	Lining of walls and skin roofs; semi-structural sandwich panels.	Relatively strong; low water-vapour transmission; low softening point.	Collapses, but burns with difficulty.
Foamed urea-formaldehyde (uf)	*In situ* filling of cavity walls for thermal insulation.	Poor physical and mechanical properties.	Resistant to ignition.
Foamed phenol-formaldehyde (pf)	Lining of walls and flat roofs and as core material for sandwich panels.	Good fire and high temperature characteristics. Relatively poor physical, mechanical properties.	Highly resistant to ignition.
Foamed polyurethanes (i) Flexible	Shaped insulation for pipework, acoustic applications, sealing and jointing.	Relatively high thermal insulation and water vapour transmission	Generally burn rapidly, producing thick dark smoke; flame-retardant grades are available.
(ii) Rigid	*In situ* insulation of roofs; as insulating boards for use in roofs, walls, underfloor applications. Core material for sandwich panels. Insulating and stabilising cavity walls. Spray-up foam has been used externally with a weather-resistant coating for walls and roofs.	Excellent thermal insulation; fairly good high temperature and water vapour transmitting characteristics.	

It is also softened by plasticisers from other polymeric materials. In contact with pvc, for example, there will be an interaction that will cause the polystyrene to dissolve partially and become tacky and the pvc to become brittle as a result of the loss of plasticiser. This can occur, for example, if polystyrene granules used for roof insulation come into contact with pvc sheathed electrical cables. It is not likely to cause a serious problem but the two materials are best kept separate either by appropriate siting of the cables or by the use of conduit.

Expanded polystyrene is manufactured in large blocks, which are then sliced into boards of the required thickness. In thicknesses greater than 19mm, its ease of manufacture gives it a competitive edge over other insulating materials.

The low density of expanded polystyrene makes it easy to fix with adhesives, though, as indicated above, these must be carefully selected so as to avoid risk of chemical attack. Where the area of contact is limited, as under uneven ceilings or on corrugated surfaces, reliance should not be placed solely on the adhesive. Particularly under corrugated skin-roofs, the build-up of heat over the insulating boards in sunny weather can be sufficient to render most of the common adhesives ineffective. In such cases, it is advisable to fix the material with large-headed nails to timber battens, taking precautions similar to those for fibre insulating boards. Building Regulations will usually require expanded polystyrene, used in this way for insulation, to be protected by a coat of plaster or other non-combustible finish.

Expanded polystyrene of lower density than 24 kg/m^3 will not by itself constitute a vapour barrier when used under a skin-roof in a warm humid building. Even with denser material a vapour barrier is desirable to avoid the risks of interstitial condensation within the material or vapour penetration at joints. The methods normally used for insulating boards—application of a gloss paint or a cocoon skin—are not suitable, because of the possible effects of solvents on the polystyrene and of the increased fire risk. A well-stuck film of polythene or aluminium foil by itself will provide a vapour barrier, though it is not always easy to obtain a neat finish with these. Water-based coatings and emulsion paints do not affect the material but by themselves contribute little to a vapour barrier.

It is possible also to stick expanded polystyrene to wall surfaces with a uniform layer of cement mortar. Rough-cut grades of the material, claimed to provide a better key to mortar and plaster than smooth-surfaced boards, may in fact give a reduced bond because of polystyrene 'dust' on the rough surfaces. A skim-coat of plaster providing a surface finish has been found to form an adequate bond with smooth-surfaced boards, though treatment with a polyvinyl acetate emulsion improves the bond.

A 5 mm skim-coat of plaster will probably have adequate impact resistance for most purposes, but where impact blows are likely to be severe, it is advisable to use a bonding coat of sanded plaster under the skim-coat.

Roof insulation

Expanded polystyrene boards may be laid directly on flat decks and concrete roofs and secured to the substructure by mopping the vapour barrier (which previously must be bonded in position) with hot bitumen and applying the boards while the bitumen is still tacky. There are problems associated with this method of insulating roofs and BS CP 144: Parts 1 and 3 (imperial and metric units, respectively) *Roof coverings; built up bitumen felt,* refers to only two possible methods of direct felting of the polystyrene. Caution is necessary because of the low softening temperature and the compressibility of expanded polystyrene. When felt is laid directly over polystyrene on any but inaccessible roofs, warning notices should draw attention to the need for boards before walking or placing ladders, etc., on the roof covering.

Tapered boards are available to provide falls to horizontal decks; material of at least 24 kg/m^3 density is recommended. Where the insulation is only partially supported, e.g. on a metal deck, material of 32 kg/m^3 or higher density should be used; a grade of extruded expanded polystyrene is manufactured for this purpose. This type of structure requires further treatment to make it weather-proof and to enable it to carry even the light traffic on a roof. A dark-coloured insulated roof may occasionally reach the maximum working temperature of polystyrene; to prevent undue heat build-up in sunny weather, a white finish to the roof is desirable, or the surface should be covered with light-coloured chippings or gravel.

Various methods of felt-laying have been suggested, using either emulsion-type adhesives or hot bitumen under conditions intended to prevent collapse of the polystyrene. One technique uses a roofing felt with a heat-sensitive backing, which seals the first layer of felt to the expanded polystyrene when subsequent layers are applied using hot bitumen. The temperature control for this method is critical and caution is necessary to ensure even heat distribution and to avoid the formation of pools of hot bitumen. An alternative is to have the first layer of felt applied to the board in the factory, where control is easier, and the joints subsequently taped and further layers of felt applied on site. Another method is to apply hot bitumen only to the felt, which is then laid on the polystyrene while it is still tacky. With any of these techniques, allowance should be made for thermal contraction of the polystyrene boards. These should be butted against one another as firmly as is practicable in laying; bonding of the felt should be prevented on either side of the joints between adjacent boards. This can be done either by laying a strip of felt about 200 mm wide over each joint, bonded along one edge only, or by using a low-friction adhesive paper tape made specifically for this purpose. White grit, or, if there is to be appreciable traffic, white asbestos-cement or concrete tiles, will reduce softening and thermal movement in hot weather. If hot mastic asphalt is used over expanded polystyrene the asphalt must be applied on a heat barrier to prevent collapse of the polystyrene. Alternative materials proposed for this barrier include a fibre quilt or fibre insulating board which are permanently incorporated in the structure.

A continental system, in which a flexible membrane is laid loose on the polystyrene and held in position by a 30 mm or greater thickness of gravel, has received favourable comment. Another development is the 'upside-down' roof, which depends on the very low water-absorption of extruded polystyrene. A board of this, with surface skin, is laid on the upper side of the impermeable roof membrane. It is held in place with gravel and does not absorb enough rain water to impair significantly its thermal insulating value. The success of these methods has not been evaluated under all conditions; certainly an advantage is that expanded polystyrene entraps no water, so that full insulation is obtained without the need for a drying-out period.

Expanded polystyrene has been used in the form of 'permanent shuttering' for concrete roofs, for which thermal insulation can be provided by placing boards of the material in the formwork before pouring the concrete. When the concrete sets, the boards are held firmly in position. A development of this idea in the United States has been the use of wire-supported boards of extruded expanded polystyrene for forming thin shell-roofs, particularly of dome, barrel-vault or hyperbolic paraboloid design. The roof shape is first set up on temporary braces with a minimum of steel supporting wires, to which boards of expanded polystyrene can be fitted, provided that there is no excessive curvature. Dome structures have also been 'spirally generated' with strips of expanded polystyrene.

Floors

Expanded polystyrene is suitable for insulating concrete floors, since it has low moisture absorption and is resistant to fungal attack. For ground floors it is normally laid as boards over the concrete base. The boards are not impervious to moisture, and a damp-proof membrane should be provided below them. If a bituminous material is used for this, it should be chosen with care to avoid possible interaction with the polystyrene.

Material of density not less than 16 kg/m^3 is recommended for this use. The boards must be protected from damage by subsequent trades. For intermediate floors, the boards can be used either to line the shuttering and provide a permanent insulating skin on the underside of the structure or slab, or they can be sandwiched between the structural base and the screed. This sandwiched form of construction offers an advantage in reducing the transmission of impact sound through the floor when a special board, that

has been submitted to controlled pre-compression, is used. A minimum thickness of 60 mm of screed is required with this form of construction.

The edges of the screed must be isolated from the walls; this may be effected by a strip of expanded polystyrene round the perimeter. Earlier fears that creep of the material under sustained loading would impair the resilience of such a layer do not seem justified and there is evidence that this form of construction will retain its effectiveness in absorbing impacts. Such a layer, if laid to form an effective 'floating floor', will also contribute towards reducing the transmission of airborne sound. In regard to the floor as a whole, however, the primary requirements for airborne sound insulation are mass and the elimination of air gaps.

When expanded polystyrene is used as thermal insulation beneath underfloor heating cables, it should be separated from the cables by at least 12 mm of dense cement/sand screed.

Walls

Expanded polystyrene may be stuck to the inner brick face of a wall with a layer of cement mortar and protected with a skim-coat of plaster; a preferable alternative is the use of a laminate of plasterboard and expanded polystyrene fixed, with the plasterboard exposed, by a dry lining technique.

Expanded polystyrene boards can be used to partially fill a wall cavity but their installation is complicated by the wall ties and the need to hold the boards against the inner leaf to maintain a cavity which, it is recommended, should be at least 50mm. The method of fixing and the type of wall ties need careful consideration. Beads or granules are also used as a cavity fill insulation.

Wall lining

Expanded polystyrene is available in sheets only a few millimetres thick for lining before wallpapering. The contribution of this to the total thermal insulation of a room is small but in an intermittently heated room it permits a more rapid rise in temperature and may, in marginal conditions, prevent condensation.

Insulation for plumbing

Expanded polystyrene is available as preformed insulating jackets for cylinders and tanks and in profiled sections for pipework. Except in systems with carefully regulated temperatures, it is not suitable for use on hot-water cylinders or pipes because of its comparatively low softening point. It can be used to prevent condensation on cold water pipes in humid environments; a water vapour seal should then be fitted to the outside. It can also be used to reduce the risk of frost damage; an external waterproof seal should be used here also if there is any possibility of the insulation becoming very wet. Although this will not harm the polystyrene, its thermal resistance will be reduced.

Acoustic uses

Expanded polystyrene does not absorb sound by porosity as do most acoustic tiles. Nor do perforations help materially. When stuck to a hard surface polystyrene tiles give no improvement of sound absorption but they can give a measure of absorption when mounted on battens with an airspace between the tiles and the backing surface. Most panel absorption in buildings occurs in the low-frequency band of sound because the absorption is due to resonance at the natural frequency of the panel; the natural frequency (and therefore the region of absorption) of expanded polystyrene tiles is higher than usual, being in the middle frequency band, because of the very light weight of the material. Nevertheless, the contribution of polystyrene tiles to sound absorption is quite small.

Ceiling tiles, to BS 3932, provide a patterned or textured surface with additional thermal insulating value. They are particularly useful in improving the appearance of cracked or uneven ceilings. They must be attached with an overall application of adhesive and, preferably, the surface should be left undecorated in the interests of fire safety. If surface finishes have to be applied, these, in order of preference, should be flame-retardant paints or matt-finish emulsion paints.

Concrete aggregate

In general, the properties of a lightweight concrete made with expanded polystyrene beads as aggregate may be compared with those of concrete made with expanded perlite, and similarly proportioned mixes are used. The manufacturers recommend wetting the beads before adding cement to the mix, but the material has so very little weight that it is not easily handled on a building site. In the event of a fire, the polystyrene beads collapse, leaving voids in the concrete, the residual strength of which may not be sufficient to permit its use for structural purposes.

Holes in concrete

Expanded polystyrene can be used to form holes and channelling in concrete. It is moulded or carved to the shape required and then nailed in position inside the shuttering before the concrete is poured. Subsequently the expanded polystyrene can be cut out, or burned out with a blowlamp. The technique has also been applied to producing patterned decorative surfaces on concrete. The material is also used to form deliberate voids in massive concrete castings—for example, bridges—to reduce weight and cost and to improve the speed of casting. Standard moulded blocks and cylinders are available for the purpose and these are used also in casting ribbed and voided floors. The polystyrene is usually left in position after casting.

Expanded pvc

Expanded unplasticised pvc is more expensive than most other cellular plastics and its application to building is at present limited to situations where its particular properties are of prime importance. It can be stronger and more rigid than other cellular plastics. It has an almost completely closed-cell structure and

a correspondingly low water vapour transmission and water absorption. It could be described as a naturally flame-retardant material and in a fire it is unlikely to contribute to the flame spread though the cell structure will collapse at an early stage. The addition of flame-retardent additives is unlikely to have any advantage. It is sensitive to some solvents used in adhesives and in service its temperature should not exceed 50 °C.

BS 3869 : 1965, *Rigid expanded polyvinyl chloride for thermal insulation purposes and building applications,* is related to two grades of the material of apparent density 24 to 48 kg/m^3 and 48 kg/m^3 and above. Expanded pvc is available in simple board form, and as the core material in sandwich panels. Its low vapour transmission would appear to provide advantages where condensation might be a problem but the most useful applications seem to be in sandwich panels, where its rigidity contributes greatly to strength. In curtain-wall panels it must be used with caution, because the thermal insulating effect of boards fastened directly behind cladding sheets can, in warm sunshine, produce surface temperatures higher than the material can tolerate. It has found more application in cold stores, where its properties can be used to good advantage.

Foamed urea-formaldehyde

Foamed urea-formaldehyde resins are mainly of interest in building because they can be foamed on site and the foam injected into cavity walls to improve thermal insulation. The process uses aqueous solutions of resin and hardener. One of these, usually the hardener, contains a surfactant which enables it to be foamed with compressed air. The other solution is mixed into the foam immediately before injection into the wall cavity where the foam sets and excess water evaporates. As the resin is comparatively inexpensive, considerable improvement in thermal insulation is possible at modest cost.

Some shrinkage and fissuring of the foam is normal during drying and this can provide paths for water to cross the cavity. Whilst there has been widespread satisfaction from its use as cavity fill wall insulation, a small proportion of installations have induced rain penetration. Filling walls exposed to driving rain entails a positive risk unless the outer leaf provides a higher resistance to rain penetration than typical facing brickwork. This risk appears to be acceptable if the wall has suitable detailing and is rendered or clad. BS 5618 *Code of Practice for Thermal insulation of cavity walls (with masonry inner and outer leaves) by filling with urea-formaldehyde (UF) foam* and Digest 127 give more details for assessing suitability.

Phenolic foam

Foamed phenol-formaldehyde resin is available in boards and slabs to BS 3927 : 1965. *Phenolic foam materials for thermal insulation and building applications.* It is usually a pink, or occasionally deep red, somewhat friable material with fine uniform cells, and it may range from having an open cell structure to almost 90 per cent of closed cells. It is most commonly used in a density of about 48 kg/m^3 and the closed-cell form is about 25 per cent better in strength and thermal insulating properties than the open-cell form.

Phenolic foam burns only with considerable difficulty, generating little smoke and negligible quantities of toxic gases, and retains its mechanical strength even for continuous use up to 150 °C. New hardeners have overcome the early problems caused by excess of acid hardener used in production, and the material is not now expected to cause corrosion on contact with metal tanks or hot pipes. Metal surfaces to which the foam is applied, and which operate at or below ambient temperature, should be painted to prevent corrosion by small amounts of residual or other moisture. The surface of the foam is not easily painted. It can, however, be used to insulate concrete structures and, since plaster will bond to it satisfactorily, it has been used as permanent shuttering for concrete and then covered with a skim-coat of plaster.

It is also available in the form of paper-faced laminates which may be used as an insulating alternative to plasterboard for lining ceilings. Sections have been made for pipe-lagging purposes and for covering ducts, and spray-coating with the foam is possible though not in wide commercial use.

Phenolic foam has been used successfully as thermal insulation on flat concrete roofs. Slabs of the material can be laid and bonded on concrete with any of the normally used adhesives and then, provided care is taken to avoid excessive local pressures which might puncture the felt, a built-up felt cover can be applied using normal techniques with hot bitumen, which will not cause the foam to collapse. The mechanical strength is not great enough to resist puncture if ladders are rested on such a roof covering but for roofs where only light traffic is expected it is strong enough. Tile finishes can be laid over the built-up roof where traffic is heavier.

Other uses have been in loft and cavity insulation, in granular form, and as insulation in glass reinforced polyester cladding panels. In the latter, the fire characteristics are probably more important than the foam's thermal properties.

Foamed polyurethanes

Flexible foams

Foamed polyurethanes have an open-cell structure which gives excellent acoustic absorption at high frequencies but since both their cost and thermal transmission are higher than most other cellular plastics, flexible urethane foams are not generally used in building. There are two exceptions : they have been fitted behind perforated panels in hospitals to control noise, and as pre-formed pipe lagging which can be carried round bends and easily shaped, and

may be used for hot or cold services. Although this is manufactured with an outer skin which provides some protection against condensation, for low temperature pipes it may be necessary to add a pvc or polythene film as a vapour barrier.

Profiled sections of 'semi-rigid' foam are used as filler blocks for closing the spaces at the ends of corrugated roofing and cladding sheets. Similar but usually harder foam has also been used in floor construction to reduce the transmission of impact sound through the floor; information is limited, however, about the long-term behaviour and resistance to creep of the material under sustained loading and more experience is required of its continued resilience under periodic vibration.

Rigid foams

In recent years, rigid polyurethane foams have been developed and have been recommended for a number of building applications. Volatile inert organic liquids blended with the resin mixture produce even and controlled foaming. The product, having pores filled with a gas mixture of low conductivity that does not readily diffuse through the cell walls, has a thermal conductivity less than that of still air. If the foam has free access to air, in time air can diffuse inwards until an equilibrium condition is reached. (This diffusion of air in and blowing agents out is generally known as 'ageing'). Even so, the eventual thermal conductivity of a properly made foam is likely to be no more than that of still air, and appreciably lower than that of any other solid insulating material at present available. In a sealed structure, such as an impermeable-faced panel, diffusion, with consequent loss of thermal insulating value, will not occur.

The principal advantages that polyurethane foams can offer over other foamed plastics are their excellent low thermal conductivity at low temperature, fairly good high-temperature resistance (up to 100°C), low vapour permeability and their property of being able to be foamed *in situ* by mixing two liquid components in monitored proportions. These components produce a foam which expands after placing, filling any holes and crevices, and which also adheres well to surfaces, although temperature and moisture-sensitivity of the process may complicate its use on building sites. It is possible to surround a complicated network of pipes with the foam to provide thermal insulation, or to fill complex cavities. This may be useful in roof-spaces, and the process has been used on a small scale for filling cavity walls. One application has been to inject *in situ* foam of about 50 gm/m^3 density with the prime purpose of stabilising a cavity wall where the outer leaf has been in danger of collapse. A lower density foam is used where the prime purpose is for thermal insulation. The properties of the material should enable filling without shrinkage cracks but some voids or water bridging can be caused by unseen obstacles within the cavity and even the lowest practical density foams cost more than many other cavity fills. Another application is filling cavity walls when a high degree of thermal insulation is required. It is likely to be uneconomic for normal cavity insulation but, when used, it should be borne in mind that the cavity must provide a barrier to water penetration. Such a foam would not permit ingress of water except at the 'bridge' formed by a void, where in severe conditions any penetration would be aggravated. While it is possible in the factory to produce a good and uniform foam, on the building site, in adverse weather conditions and with wide variations in the wetness of surfaces, a great deal of skill is required. A technique using a 'frothed' foam with better flow properties than the mixture normally injected into the cavity can produce a more even *in situ* filling with few voids, but considerable skill is necessary to ensure a good fill.

Another application is in spraying a layer of insulation under or on to cleaned and prepared skin roofs or walls. Although application in factory conditions is preferred, the technique is feasible *in situ* if adequate weather protection is provided. The appearance may be rather uneven but this can be improved internally by plastering. Priming the foam surface with polyvinyl acetate emulsion, or abrasion to provide a mechanical key, is recommended to ensure adhesion of the plaster to the foam. Externally the foam has to be weatherproofed, for which commercial systems are available.

To prevent interstitial condensation in humid conditions, a 'cocoon' or paint film may be applied either to the foam surface or to a plaster finish. Because of the slightly toxic nature of one component of the foam, it is necessary to evacuate the building during spraying and for the operative to wear a protective suit with a helmet. A disadvantage is that the visor may rapidly become obscured by splashes from the spray gun, resulting in a rather intermittent spraying process. However, the process has been used satisfactorily for a number of industrial and agricultural applications.

Nowadays, the bulk of foamed polyurethane used in building is supplied in the form of cut sheets for the insulation of roofs, walls and under-floor heating systems, and also as boards faced with such materials as waterproof paper, applied automatically to the foam during manufacture. Applications include use in flat roof construction under built-up felt finishes and as a substitute for plasterboard in ceilings. A British Standard (BS 4840) defines suitable quality of foamed rigid urethane for use in cold stores; other standards in the course of preparation cover the use of such boards with laminated facings for general building purposes and for use as wall and ceiling insulation.

A point to be noted is that paper-faced polyurethane is very much lighter than plasterboard. When it is used in ceilings it may permit more sound-transmission between terraced or semi-detached dwellings via the party wall in the roof space. Normally this wall is left unplastered, but plasterboard can make

up the sound insulation to the required standard; this might not be achieved with polyurethane.

The adhesion of foamed polyurethane to smooth surfaces is an advantage in manufacturing processes for lightweight sandwich panels. This application is referred to below.

Isocyanurate foams

These are made from starting materials chemically similar to those for polyurethanes and they have comparable physical properties. They are notable for their thermal stability and because of better resistance to oxidation they have improved spread-of-flame characteristics. They are available as blocks, sheets and laminates.

Sandwich panels

Several of the rigid cellular plastics are used in sandwich panels, where the interaction of skin and core can produce considerable rigidity. Using suitable adhesives, sheets of plywood, plasterboard, asbestos-cement or solid plastics are bonded to the surfaces of expanded polystyrene or foamed pvc to form panels for which numerous advantages are claimed. Such panels are also made by foaming polyurethanes between two skins, without the need for adhesives. These panels are certainly light in weight and have a high strength to weight ratio and good thermal insulating properties but, unless the outer skins are quite massive, they provide little insulation against airborne sound. Uneven thermal movement may cause some bowing although the flexibility of the foam will accommodate much of the movement. These considerations apply also to doors, which are available with expanded polystyrene cores. Sandwich panels of this type are widely used for internal partitioning but are used less for external cladding because of difficulties in jointing, thermal movement and the need to provide attractive weatherproof outer surfaces.

Another application for cellular plastics in large panel systems of construction is as an insulating lining for precast concrete panels, with a lightweight inner skin fixed to the plastics foam. On the Continent many systems employ wall units consisting of expanded polystyrene sandwiched between concrete slabs.

'Structural foams'

Structural foamed plastics are rigid cellular plastics which are denser than plastics used for thermal insulation and for cores in sandwich panels, but less dense than unexpanded material. With the exception of polyurethane, they are thermoplastics such as pvc, polystyrene and polyolefins. Despite their name, structural foam (SF) plastics are not intended for structural applications as the term is understood in the construction industry but they do possess sufficient strength and rigidity to be used as alternatives to timber, metals and unexpanded plastics in such applications as window frames and window boards, architraves and skirting, non-structural cladding and internal fitments such as shower cubicles.

They can be fabricated by extrusion and injection moulding, the latter being commonly used for producing fitments such as WC seats. There are two common methods by which simple or complex profiles can be extruded: the 'Celuka' process which leads to a product with an integral skin of virtually non-cellular material surrounding a cellular core, and the 'free expansion' technique which gives little density variation throughout the extruded section. For both types of extrusion, a range of blowing agents is available, the most common being sodium bicarbonate. It can be claimed that SF plastics combine the best features of timber and conventional (non-cellular) plastics in that they do not rot, are easy to work with tools, can be thermoformed and waste can be recycled; better thermal insulation and a higher stiffness to weight ratio are possible with SF than with conventional plastics and installation and maintenance costs should be comparatively low for prefabricated components.

On the other hand, because of their relative novelty, information is lacking on their long-term performance. The insulating core will tend to give rise to higher skin temperatures on exposure and this might lead to slightly higher rates of weathering and a higher tendency to reversion (permanent shrinkage at high temperature) than would be experienced with extruded non-cellular plastics but further evidence is required before definitive statements to this effect can be made.

On fire behaviour, pvc and fire-retarded grades of other SF thermoplastics should be satisfactory for small areas, such as skirting boards, provided that no gaps are left through which fire could be transmitted once the plastic material has melted away. For larger areas, such as cladding, some manufacturers claim satisfactory fire performance of their SF products, according to BS 476, Parts 6 and 7, but careful attention to design is required if the provisions of Building Regulation E15 are to be met.

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